

Vibration Analysis of Unbalance on Axial Fan Engine 5.5 KW

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Abstract— The unbalance on an axial fan engine causes vibration and noises in a small open wind tunnel construction circuit. The unbalance is not only speeding up the damage to the engine but also disrupt the convenience surrounding the engine, especially for the engine users. In this research, measurement analysis is done to find the cause of the unbalance. Initial vibration measurement results show the amplitude exceed[s] the ISO 10816-3 standard limit (0.292 G-S equal to 15.45 mm/s). After going through the balancing process, the unbalance of the axial fan decreases by 84% with the amplitude of 0.047 G-S equal to 2.5 mm/s, so the engine vibration and the vibrations of its surrounding rope.

Keywords— Unbalance, axial fan engine, amplitude, overall vibration, ISO 10816-3.

I. INTRODUCTION

An axial fan engine is generally used to flow fluid from one place to another by changing the velocity of the fluid flow. One of the applications of axial fan engine is as a complementary tool of an open type wind tunnel construction, used to drain the fluid to the test section room.

PT. Chroma is one of the tunnel manufacturers that uses an axial fan engine. One of the wind tunnels it built has a vibrations problem at the axial fan engine with a value of 0.292 G-S \approx 15.45 mm/s, creating bad impacts on health and safety at work especially for the machine users. So the vibration must be decreased.

Generally, there are four factors of unbalance that cause damages to an engine, namely unbalance in temperature, noise, amount of oil, and vibration.

The most severe damage is caused by vibration which may be the result of miss-alignment, contaminated lubricant oil, gear mesh defect, blade defect, stator defect, component resonance, rotor defect, belt vibration, and bearing defect (see table 1).

Table 1. Main causes of engine damage^[2]

Damage to the machine-The main cause of damage										
Unbalance	Miss-alignment	Lubrication	Oil content	Gear mesh defect	Blade defects	Stator defect	Component resonance	Rotor defect	Belt vibrations	Bearing defect
Temperature	X	X	X	X	X	X	X	X	X	X
Noise	X	X	X	X	X	X	X	X	X	X
Oil Analysis	X	X	X	X	X	X	X	X	X	X
Vibration	X	X	X	X	X	X	X	X	X	X

The axial fan engine construction that is installed in the open type wind tunnel has a direct connection between the axial fans with the engine through a coupling like a rotor connected to the stator. According to reference data the damage to direct connection machines is usually caused by an unbalance, bearing damage, and excessive aerodynamic load (see Figure 1).^[2]

Referring to the figure 1, excessive vibration on the axial fan engine 5.5 KW is estimated by the occurrences of a type of static unbalance, resulting from an engine misdeeds (such as the un-similarity in an angle between blades) or due to the imperfection in fabrications of engine components.^[2]

The measurements of vibration of the axial fan engine owned by PT. Chroma has been carried out to determines the static unbalance on the engine, and further to reduces the vibration, so it may work in a safe operation range. This may improve the health and safety of machine users.

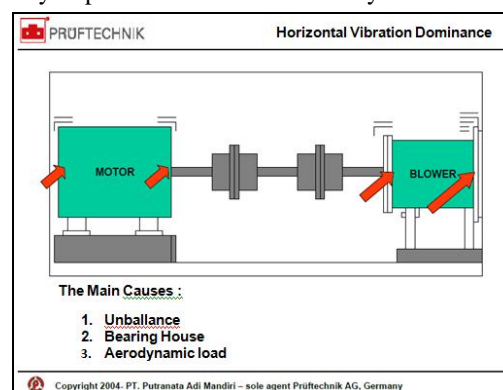


Fig.1: Dominant vibration in horizontal direction.^[2]

The main goal of measuring the unbalance carried out by PT Chroma on axial fan engines is to meet the standards of the regulations of the minister of environment of the Republic of Indonesia to keep up human health especially who works in Indonesia.

To protect Indonesia's health and safety from the effects of high vibration, the minister of environment of the Republic of Indonesia has made two rules that can be used as a law of human protection (see table 2 and table 3).^[6]

Table 2 shows the regulation of the minister of environment of the Republic of Indonesia which regulates the relationship between standardized vibrational levels with an environment friendly and health. Where type of environment friendly and health is made with 4 classifications (do not disturb, disturb, uncomfortable, painful).

Table 2. Standards of vibration for comfort and health (decree of the state minister for the environment of the Republic of Indonesia, KEP-49 / MENLH / 11/1996).^[6]

Frequency (Hz)	Vibration Rate Value, in micron (10 ⁻⁶ meter)			
	Do not disturb	Disturb	Uncomfortable	Painful
4	< 100	100 – 500	500 – 1000	> 1000
5	< 80	80 – 350	350 – 1000	> 1000
6,3	< 70	70 – 275	275 – 1000	> 1000
8	< 50	50 – 160	160 – 500	> 500
10	< 37	37 – 120	120 – 300	> 300
12,5	< 32	32 – 90	90 – 220	> 220
16	< 25	25 – 60	60 – 120	> 120
20	< 20	20 – 40	40 – 85	> 85
25	< 17	17 – 30	30 – 50	> 50
31,5	< 12	12 – 20	20 – 30	> 30
40	< 9	9 – 15	15 – 20	> 20
50	< 8	8 – 12	12 – 15	> 15
60	< 6	6 – 9	9 – 12	> 12

Table 3 shows the categories of vibration limits as regulated by the minister of environment of the Republic of Indonesia. The limit associates with damage may cause, shown in four categories (A = no damage, B = causing cracks, C = causing structural damage, D = causing damage to load-bearing walls).

Table 3. Mechanical vibration level based on impact of damage (decree of state minister of environment of Republic of Indonesia, KEP-49 / MENLH / 11/1996).^[6]

Frequency (Hz)	Vibration Velocity Limit, in mm / sec			
	Category A	Category B	Category C	Category D
4,0	< 2,0	2,0 – 27	27 – 140	> 140
5,0	< 7,5	7,5 – 25	25 – 130	> 130
6,3	< 7,0	7,0 – 21	21 – 110	> 110
8,0	< 6,0	6,0 – 19	19 – 100	> 100
10,0	< 5,2	5,2 – 16	16 – 90	> 90
12,5	< 4,8	4,8 – 15	15 – 80	> 80
16,0	< 4,0	4,0 – 14	14 – 70	> 70
20,0	< 3,8	3,8 – 12	12 – 67	> 67
25,0	< 3,2	3,2 – 10	10 – 60	> 60
31,5	< 3,0	3,0 – 9	9 – 53	> 53
40,0	< 2,0	2,0 – 8	8 – 50	> 50
50,0	< 1,0	1,0 – 7	7 – 42	> 42

II. THEORETICAL BASIS

Vibration is an alternating motion that passes through the same trajectory. This kind of movement is called periodic motions.

Between these periodic motions there is a movement called a harmonic motion. So the vibration of an object is said to be a simple harmonic function, with the following deviation equation below.

$$Y = A \cos \omega t \dots\dots\dots(1)^{[3]}$$

Where A is the amplitude, and ω is the angular frequency.

The existences of the angular frequency at harmonic function can be used to calculate the period or time of vibration of back and forth with this Equation :

$$T = 2\pi / \omega \dots\dots\dots(2)^{[3][5]}$$

The frequency that occurs can also be approached by this equation.

$$f = 1 / T = \omega / 2\pi \dots\dots\dots(3)^{[3][5]}$$

The speed of a simple harmonic moving object can be obtained from the first derivative of this deviation Equation (1).

$$v_y = - A \omega \sin \omega t \dots\dots\dots(4)^{[3]}$$

While the accelerations of simple harmonic moving objects comes from the second derivative of Equations (1).

$$a_y = - A \omega^2 \cos \omega t = - \omega^2 Y \dots\dots\dots(5)^{[3]}$$

The above formula is usually used to measure vibrations that occur on a machine, so that the unbalance in the engine due to vibration can be investigated.

The decrease in the unbalance correction ratio in a single plane balancing can be approximated using the following equation:

$$URR = 1 - U_2/U_1 \dots\dots\dots(6)^{[4]}$$

Where U_1 initials value unbalance and U_2 is the value of unbalance after correction.

III. MEASUREMENT METHOD

Usually to measure vibration on a machine, a measurement acquisition system is needed which consists of a vibration machine, trigger, and accelerometer, where the system will change the vibration signal data into electrical signal data.

The measurement acquisition system can measure vibration amplitude of a stationary or moving specimen or engine. The amplitude can be decomposed into some parameters of velocity and acceleration according to the directions of the required axis, so the placements of an accelerometer on the specimen or machine shows the direction axis of vibration measured of the specimen or machine.

Velocity parameters is one of the best indicators to know the problem of vibration at medium velocity engine.

The method of placing the accelerometer measuring instrument is determined according to the direction of the axis of the specimen or machine to be measured. To measure a vibration amplitude in the directions of the specimen or machine axis, the accelerometer is placed parallel to the x axis, and to measure a vibration amplitude in the horizontal directions of the specimen or machine axis, the accelerometer is placed parallel to the y axis, while to measure vibration amplitude in the vertical direction of the specimen or machine the accelerometer is placed parallel to the z axis.

For this axial fan engine case, the vibration data required is in the vertical direction, so the accelerometer is placed parallel to the z axis in the engine's front bearing area. While the trigger is placed on the front of an axial fan engine hub (see figure 3). Then the device is connected to the CSI-2130 analyzer as a vibration counter.

The acquisition data process of an axial fan engine is started while the accelerometer sensor receives the vibration amplitude signal data from the engine, then the vibration signal data is converted into electrical signal data, then the electrical signal data is sent to the CSI-2130 analyzer to be calculated iterative. Furthermore the CSI-2130 analyzer engine provides information simultaneously about the phase angle of the placements of the correction load positions and the value of the correction load, so that the unbalance value on an axial fan engine can be known and reduced.

SPECIFICATIONS OF SPECIMEN

Tabel 4. Technical information of the test specimen

Engine	: Axial fan
No. of blade	: 14 pieces
Power	: 5.5 KW
Speed motor	: 3000 RPM
Transmission system	: Direct
Speed balancing	: 1700 RPM
Diameter impeller	: 28.4"

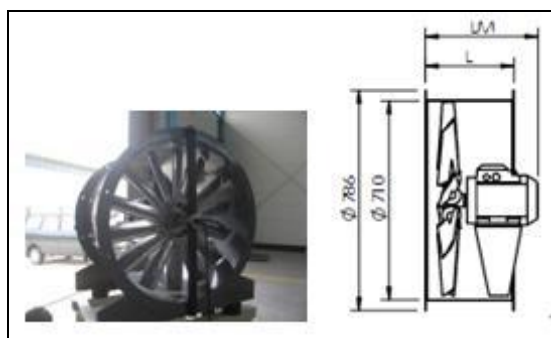


Fig.2: Construction of an axial fan engine.

IV. SETUP MEASUREMENT

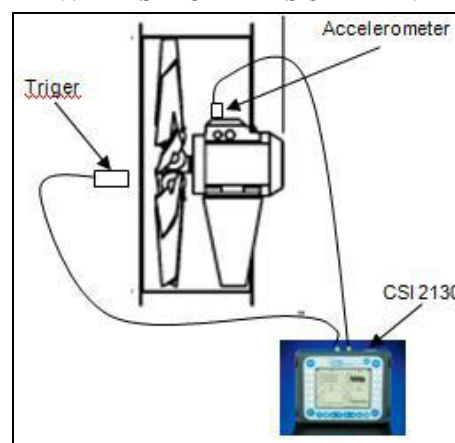


Fig.3: Setup measurement.

The measurements in this static unbalance experiment use the single plane method with several steps.

The first step, the axial fan engine is turned on, and then measures the initial unbalance to the engine by the measurement acquisition system (accelerometer, trigger, CSI 2130), the measurements were made in the front bearing positions of axial fan engine in a vertical direction only (see figures 3 and 4a).

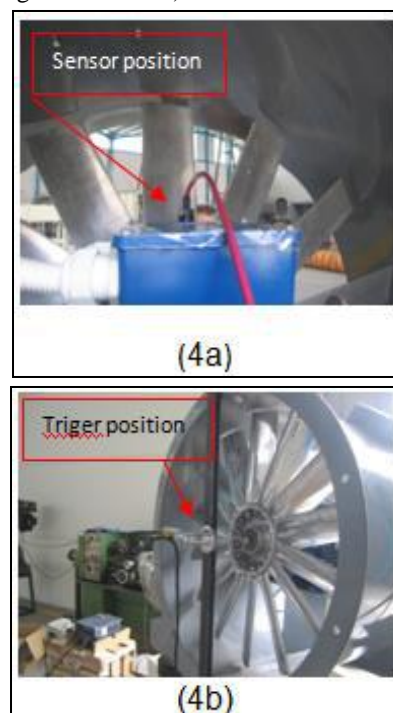


Fig.4: The locations of the vertical direction sensor on bearing no.1 of an axial fan engine (4a) and the locations of trigger (4b).

From the measurement results obtained by the value of amplitude of initial unbalance 0.2924 G-S (15.45 mm / s) at 318° phase angle (see point 1a Fig. 10a and 10c), then the engine is turned off.

The value of unbalance obtained from the measurements of 15.45 mm/sec is quite large beyond the allowable vibration limit for the axial fan engine, therefore the value must be reduced to the allowable limit.

The second step is to provides a trial weight as shown in fig. 5. This trial weight will be used to calculate the correction weight, at this moment the trial weight is used 20.1 grams at an angle of 0° on the axial fan engine hub (see first positions/ no. blade 14). Then turn on the engine again.

While the engine is running, the initials value of unbalance is measured by using a trial weight. The measurement locations is also at the front bearing positions of the axial fan engine on vertical direction.

From the measurement, it is obtained the value of initials unbalance velocity of the axial fan engine, that is 0.479 G-S (25.34 mm/s) 326° . Besides that, it is obtained the correction load phase angle and the correction load value as explained in step three, Afterward, the engine is turned off.



Fig.5: Location of trial weight on blade no. 14 at a hub axial fan engine.

The third step is to provides the correction weight, that is 25.29 grams at 231.4° (at first positions/ blade no. 6), and 5.42 grams at 205.7° (at second positions/ blade no.7) as shown in fig. 6, then put the engine on again. Then the initials unbalance of axial fan engine is re-measured at front bearing positions on vertical direction.

The result shows that the initials unbalance value decreases to 0.047 G-S (2.5 mm/s) at 31° phase angle (see point 2 - figure 10b and 10c) from the previous initials unbalance velocity value of 0.2924 G-S (15.45 mm/s). It means that the initials unbalance positions moves from the positions of point 1 to point 2. The displacements from point 1 to point 2 wants to show that visually the

change in the value of the amplitude of the unbalance vibration becomes better especially if the visual change in the value of the amplitude of the unbalance vibration approaches the point (0,0). The percentage change in the value of vibration amplitude is decreased by 84%. Judging from this, the balancing process is considered successful.

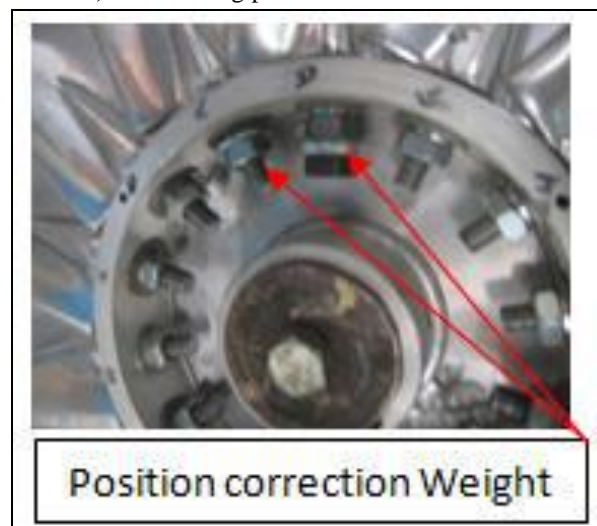


Fig.6: The locations of the correction weight in blade no. 6 and 7 at a hub of axial fan engine.

The fourth step is to measure the natural frequency and velocity vibration of the buffering of the axial fan engine by the bump test method. From the measurement found there are rapid increase in frequency from 7.81 Hz to 19.70 Hz, as well as a rapid increase of velocity from 0.0030 in / s to 0.0060 in /s. This shows that probably there is an effect of natural frequencies on the less rigid axial fan engine buffer (see table 5 and figure 11).

V. RESULTS AND DISCUSSION

Measurement and recording with FFT spectrum data curve is very helpful in conducting vibration monitoring or analyzing a problem on the machine. Therefore FFT spectrum data curve is often used by experts as a guide to quickly and accurately indicate an abnormal problem of vibration on the engine see figure 7, 8, and 11).

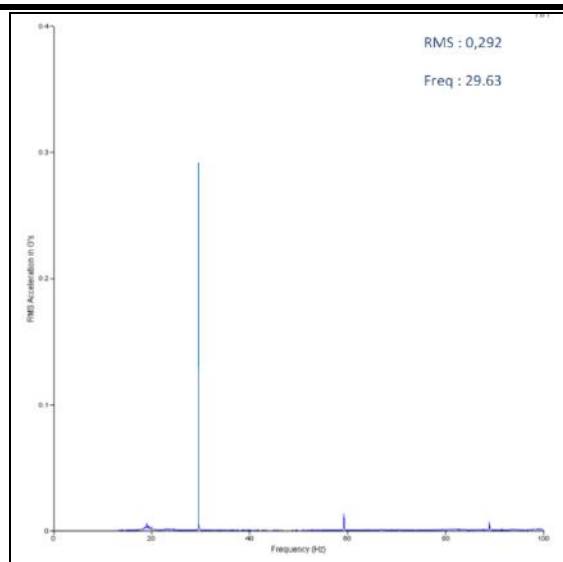


Fig.7: Axial fan engine vibration spectrum data owned by PT. Chroma before correction

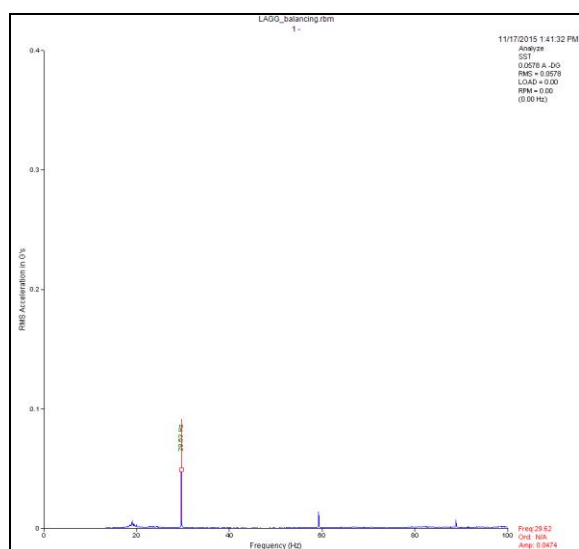


Fig.8: Axial fan engine vibration spectrum data owned by PT. Chroma after.

Evaluation of vibration and bump testing

The evaluations of measurement and correction of static unbalance of axial fan engine of PT. Chroma refers to the ISO 10816-3 and the guidance of the decree of the state minister of the environment, KEP-49/MENLH/11/1996.

Initial static unbalance velocity axial fan engine measurement results obtained value of 15.45 mm/sec, while the static correction unbalance velocity measurement results obtained a value of 2.5mm/sec. so that there is a very large decrease in the value of static unbalance velocity.

According to the ISO 10816-3, the vibration velocity value on axial fan engine with 2.5 mm/s is included in group 4 with flexible foundation classification with the allowed vibration velocity range of (0 - 4.5 mm/s), so the fan operating area of the axial engine is in a region B, (see table 6).^[7]

Meanwhile, according to the decree of the minister of environment KEP-49/ MENLH/11/1996 that the value of vibration velocity on the axial fan engine 2.5 mm/s is included in category A and does not cause damage (see table 3).^[6]

Evaluation of measurement of vibration bump test to the axial fan engine buffer, showed the increase rapidly in vibration and frequency from 7.81 Hz to 19.70 Hz with rapid increase of the velocity from 0.0030 in/s to 0.0060 in/s. This shows the effect of natural frequencies on the less rigid axial fan engine buffer (see table 5 and figure 9).

Based on the results, it comes to consideration that the axial fan engine buffer needs to be strengthened so that the natural frequency value of the axial fan engine buffer occurs outside the engine's operation frequency (see figure 9 and 11).



Fig.9: Buffering of axial fan engine that needs to be reinforced.

Table 5. Resume data bump test results for axial fan engine owned by PT. Chroma.

Spectral Peaks
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11/17/2015 3:04:15 PM
0.00 RPM
Units: Pk Velocity in in/sec

Peak No.	Frequency (HZ)	Peak Value	Order Value
1	0.56	0.2942	-1.000
2	2.06	0.0415	-1.000
3	2.69	0.0247	-1.000
4	2.94	0.0201	-1.000
5	3.31	0.0161	-1.000
6	3.56	0.0140	-1.000
7	3.94	0.0115	-1.000
8	4.19	0.0101	-1.000
9	4.57	0.0084	-1.000
10	4.94	0.0075	-1.000
11	5.19	0.0068	-1.000
12	5.56	0.0059	-1.000
13	5.94	0.0054	-1.000
14	6.19	0.0050	-1.000
15	6.44	0.0043	-1.000
16	6.69	0.0040	-1.000
17	7.07	0.0040	-1.000
18	7.45	0.0035	-1.000
19	7.81	0.0030	-1.000
20	19.70	0.0060	-1.000
21	24.31	0.0094	-1.000
22	25.94	0.0054	-1.000
23	26.56	0.0058	-1.000
24	27.31	0.0048	-1.000

Range of natural frequency of engine buffer

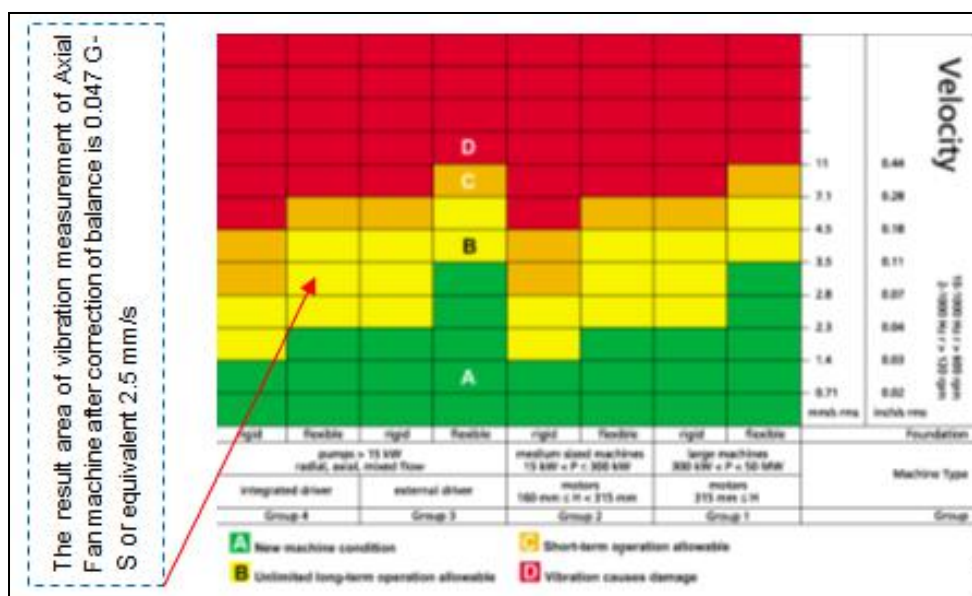
Table.6: Vibration value based on ISO 10816-3.^[7]

Table.7: The result of vibration data before and after the measurements of on-site balancing at bearing positions 1 of axial fan engine owned by PT. Chroma.

Sensor Location	Bearing 1		Explanation
Sensor position	Vertical		
Vibration before balancing	0.292 G-S	15.45 mm/s	Vibration causes damage
Vibration after balancing	0.047 G-S	2.5 mm/s	Operation allowable

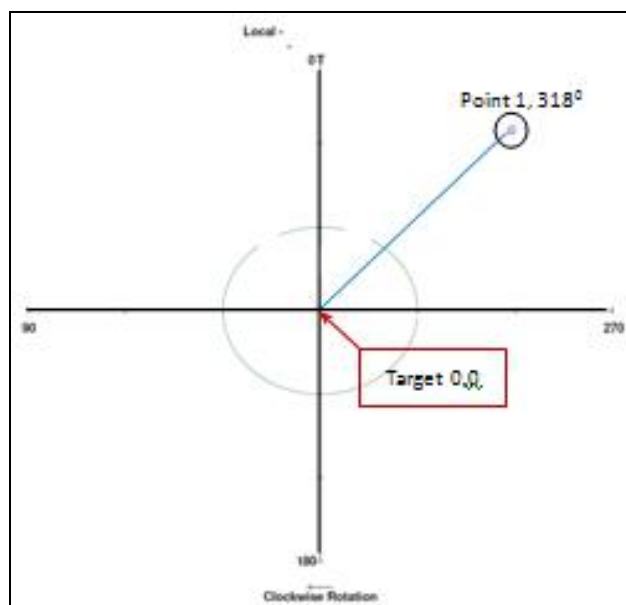


Fig.10a. Initial unbalance position

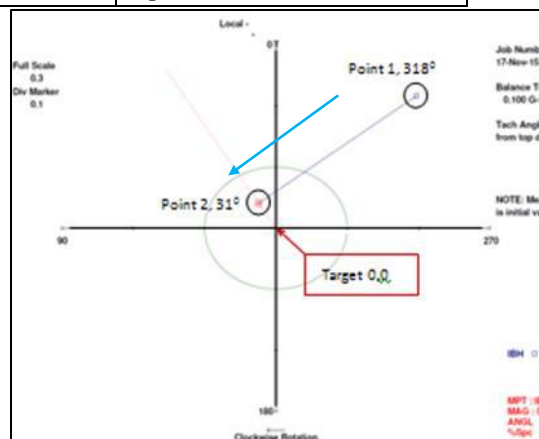


Fig.10c. Shifting of unbalance position

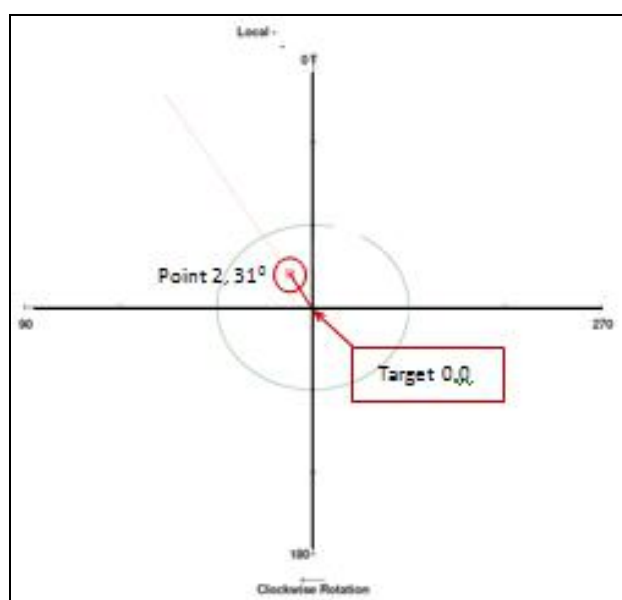


Fig.10b. Unbalance position after correction

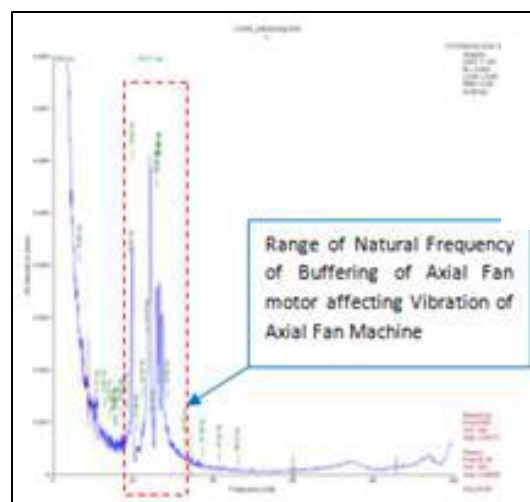


Fig.11: Resume of spectrum vibratory bump test data of buffering of axial fan engine

VI. CONCLUSIONS AND RECOMMENDATIONS

From the results of the above measurements, it can be concluded several points as follows:

1. The overall engine vibration value that occurs in the axial fan engine before is corrected by on-site balancing method is 0.292 G-S equal to 15.45 mm/s (rms); it is indicated that engine potentially speeding up the engine failure if it is not repaired immediately.
2. At the engine vibration of 0.292 G-S equal to 15.45 mm/s (rms), it indicates that the axial fan engine has

the potential not in safe range, so not comply with health and safety requirements.

3. The dominant vibration in the vertical direction is due to the unbalance in the axial fan engine blade hub.^[2]
4. After measurement and correction of unbalance with on-site static balancing method, the overall vibration of the engine decreases by 84% with a value of 0.047 G-S, equivalent to 2.5 mm/s.^[7]
5. With a vibration value 0.047 G-S equal to 2.5 mm/s, it indicates that the axial fan engine is in safe range, so it complies with health and safety requirements.^[6]
6. Referring to the ISO 10816-3 standard and the guidance of the decree of the state minister of the environment, KEP-49/ MENLH/11/1996 that the evaluations of measurement and correction of static unbalance of axial fan engine of PT. Chroma shows good results. With the decrease of the static unbalance velocity at the machine from 15.45 mm/s to 2.5 mm/s, so the axial fan engine is safely to operate because it is in category A and that it mean does not cause damage (see table 3 and table 6).^{[6][7]}
7. The existence of a less rigid buffer of the axial fan engine may affect the unbalance of the axial fan engine at a particular frequency and vibration velocity indicated by the rapid rise of the two parameters (see table 5).^[1]

RECOMMENDATION

1. The axial fan machine work activities must be monitored regularly (recommended every month) to find out the trend of engine vibration spectrum data. If the data shows a trend of increasing unsafe vibration operations, it is immediately possible to analyze the source of the bad vibration spectrum data so that identification of repairs to the machine can be known precisely, then the engine is protected from damage (see figure 7).^[1]
2. If there is a cause of vibration in the engine due to static unbalance, it is recommended to do onsite static balancing procedure as above, then the problem of unbalance on the machine can be overcome immediately, so that the engine can work again with good accuracy and the delay time of the engine is not lost too long.
3. Strengthen the buffering of axial fan engine to minimize static unbalance interference on the rotor.

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